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Technical and economic performance of residential solar water heating in the United States

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ABSTRACT

This paper examines the regional, technical, and economic performance of residential rooftop solar water heating (SWH) technology in the U.S. It focuses on the application of SWH to consumers in the U.S. currently using electricity for water heating, which currently uses over 120 billion kWh per year. The variation in electrical energy savings due to water heating use, inlet water temperature and solar resource is estimated and applied to determine the regional "break-even" cost of SWH where the life-cycle cost of SWH is equal the life-cycle energy savings. For a typical residential consumer, a SWH system will reduce water heating energy demand by 50–85%, or a savings of 1600–2600 kWh per year. For the largest 1000 electric utilities serving residential customers in the United States as of 2008, this corresponds to an annual electric bill savings range of about $100 to over $300, reflecting the large range in residential electricity prices. This range in electricity prices, along with a variety of incentives programs corresponds to a break-even cost of SWH in the United States varying by more than a factor of five (from less than $2250/system to over $10,000/system excluding Hawaii and Alaska), despite a much smaller variation in the amount of energy saved by the systems (a factor of approximately one and a half). We also consider the relationships between collector area and technical performance, SWH price and solar fraction (percent of daily energy requirements supplied by the SWH system) and examine the key drivers behind break-even costs.

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Abbreviations: DOE, Department of Energy; DSIRE, Database of State Incentives for Renewable Energy; EIA, Energy Information Administration; ITC, investment tax credit; MW_{th}, megawatt thermal; NPB, net present benefit; NPC, net present cost; NPV, net present value; NREL, National Renewable Energy Laboratory; NSRDB, National Solar Radiation Data Base; O&M, operation and maintenance; SAM, Solar Advisor Model or System Advisor Model; SRCC, Solar Rating and Certification Corporation; SWH, solar water heating; TMY, typical meteorological year; U.S., United States.

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1. Introduction

Water heating accounts for approximately 20% of all household energy use in the United States and 16% of all household energy expenditures [1]. Of this energy, roughly 20% is electricity and 67% is natural gas. While electricity represents a smaller fraction of the total water heating energy consumption than natural gas, the energy consumed is still significant, at approximately 122 billion kWh in 2005 [1] or $14 billion spent each year for electric water heating using 2010 average electricity rates [2]. For additional context, the use of electricity for residential water heating in the U.S. in 2005 was slightly greater than entire electricity demand in Poland in that year, or equivalent to the 23rd largest country in terms of electricity use [3].

Solar water heating (SWH) technology has the potential to substantially reduce household water heating electricity consumption. Solar water heaters use solar energy to preheat water before it enters a conventional water heater, thereby substantially reducing energy usage and expenditures. SWH also provides external benefits of reduced emissions of CO_2 and other pollutants.

Market adoption of SWH in the United States remains minimal, with only 100 MW_{th} added in 2007, as compared to 16,000 MW_{th} added in China and 2000 MW_{th} added in Europe [4]. A number of reasons for this low penetration include limited retailer presence, and perceptions regarding aesthetics and reliability [5]. However, a primary driver remains the high initial cost—the life-cycle benefits often do not greatly exceed the capital cost of the system, and benefits such as reduced reliance on fossil fuels and reduced carbon dioxide emissions are external to the consumer and difficult to quantify.

Detailed discussion of performance and potential market adoption of SWH exists for a number of countries including Greece [6], Oman [7], Taiwan [8], China [9], the United Kingdom [10], and India [11]. While analysis of SWH in the U.S. exists [12,13], we could find no recent, comprehensive overview of the technical and economic performance of residential SWH systems in the U.S.

This paper evaluates the regional, technical, and economic performance of residential SWH in the United States. This article presents selected results from and expands on a previous study [14]. Technical performance evaluated includes the solar fraction and electricity energy saved, while the economic performance of SWH is assessed in terms of a break-even cost. The break-even cost for SWH is defined as the point where the life-cycle value of the energy saved with a SWH system equals the life-cycle cost of a SWH system. The break-even cost is a function of many variables, including, but not limited to the solar resource, local electricity rates, hot water usage, and available incentives. As a result, for a country like the United States where these factors vary regionally, there can be considerable variation in break-even cost. We consider break-even for the largest 1000 electric utilities in the United States (serving 97% of the total residential demand as of 2008). We also examine the individual components of break-even cost, including various incentive structures, and analyze the relationship between SWH price and solar fraction (percent of annual energy requirement supplied by the SWH system). Finally, we examine the sensitivity of the break-even cost to major drivers including system performance, hot water usage, financing parameters, fuel prices, and policies.

2. Base case residential SWH performance

For the base case scenario, break-even SWH system costs were determined for the solar resource and fuel price location corresponding to the largest electric utility in each state, using a single set of assumptions for financing, system orientation, hot water usage, and incentives. The following sections describe the base case assumptions and discuss the technical and economic performance of the SWH system.

2.1. Regional variation in water heating fuel

Of the 110 million households in the United States that require fuel for water heating, 39% use electricity and 54% use natural gas [1]. Fig. 1 illustrates the regional distribution of residential water heating fuel type for each of the nine census regions plus California, Texas, Florida and New York [1]. The pie charts indicate the percentage of households in each region that use a given fuel type.

As illustrated in Fig. 1, at least some fraction of houses in any given region use electricity for water heating (the national average water heating demand is 2814 kWh per house per year) [1]. The relative number of houses using electric water heating is particularly high in the South (Florida, the South Atlantic, and the East South Central regions), and the Pacific Northwest.

2.2. Regional variation in water heating energy demand

The solar fraction and energy savings of a SWH system is influenced by the annual energy demand. Energy demand for hot water heating is a function of climate, inlet water temperature, house size, and usage patterns of the residents. To determine the annual amount of energy required for water heating we used the Solar Advisor Model[1] (SAM), an analysis tool for solar energy systems developed by the National Renewable Energy Laboratory (NREL). Detailed discussion of the solar water heating model is provided in the model documentation [15]. For this analysis, collectors are assumed to be flat plate collectors with 3.72 m^2 of collector area plumbed in parallel, with uniform flow through each collector at the tested flow rate. The collector loop is assumed to be charged with glycol having Cp = 3.4 kJ/kG-°C, with no correction to the collector parameters. We assume a two-tank system with an auxiliary electric heater (4.5 kW) and a 227 L storage tank. The water heater set temperature is 48.9 °C, and we assume a water heater energy factor of 90%. For our base case, we assumed the collectors are south-facing with a tilt angle of 26.5° (this corresponds to a roof pitch angle of about 6½, or roughly midway between the most common roof angles of 4/12 to 8/12). Once SAM calculates the performance of the base system, we assumed an annual degradation of 0.5% per year, which is likely a conservative assumption since no significant degradation has been shown to occur [16].

For additional discussion of solar water heating operation and performance, see the literature review provided by Jaisankar [17].

To determine the energy required for water heating *without* a SWH system, SAM sets the contribution from the solar system to zero and utilizes typical meteorological year (TMY3) climate data for 1020 stations throughout the United States [18]. This large number of sites (indicated by the dots in Fig. 2) captures the variation in climate and solar resource across the U.S. Given these climate parameters and assuming a constant load profile for a single-family house with a daily hot water use of 227 L, Fig. 2 shows the variation in annual hot water energy demand for the United States.

As illustrated in Fig. 2, the energy required to heat water in warmer climates is significantly less than in colder climates. For the United States, this energy demand ranges from less than 2400 kWh (in southern California, Texas, and Florida) to over 3800 kWh (in North Dakota, northern Minnesota, and northern Maine). The Rocky Mountain region generally has higher water heating energy demand due to cooler inlet water temperatures.

[1] Since the analysis was performed the name has been changed to the System Advisor Model.

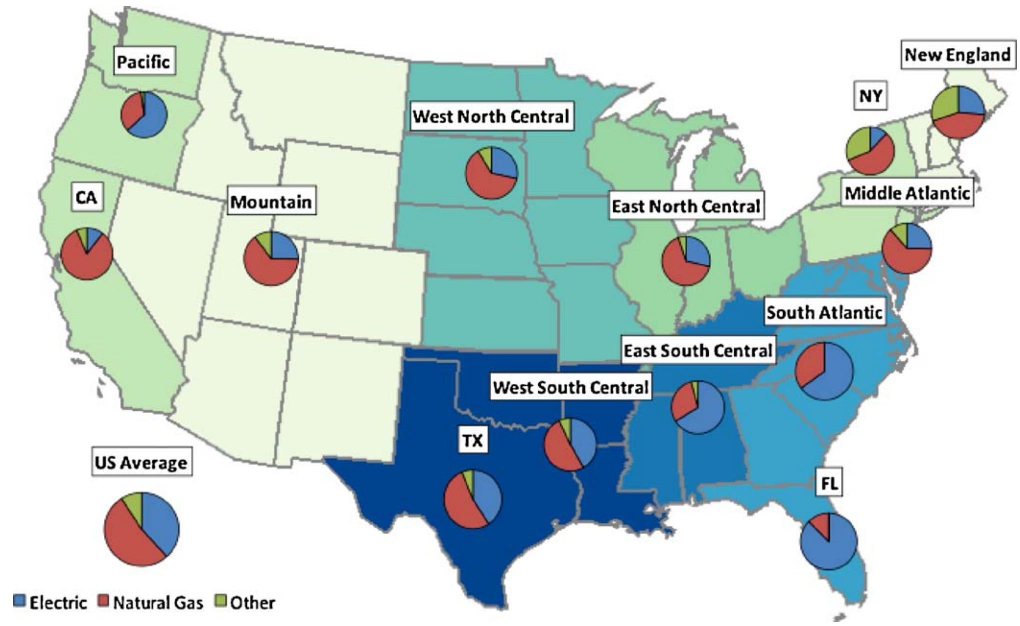

Fig. 1. Regional distribution (by U.S. census region) of the number of houses using a particular water heating fuel type [1].

2.3. System performance and energy saved

Using the system described in Section 2.2, SAM was used to determine the amount of energy saved by a SWH system. Active indirect systems are common throughout most of the United States; however, in warmer climates (notably Hawaii and southern Florida) the system simulated by SAM is not necessarily representative of what might actually be installed. Direct systems are much more common in areas where only occasional freeze protection is required; however, it should be noted that some state incentive programs restrict the use of direct systems (California and Oregon, for example). Actual system size may also vary by location – while 3.72 m^2 is a common system size, it may be oversized in regions with high solar irradiation (such as the southwestern United States)

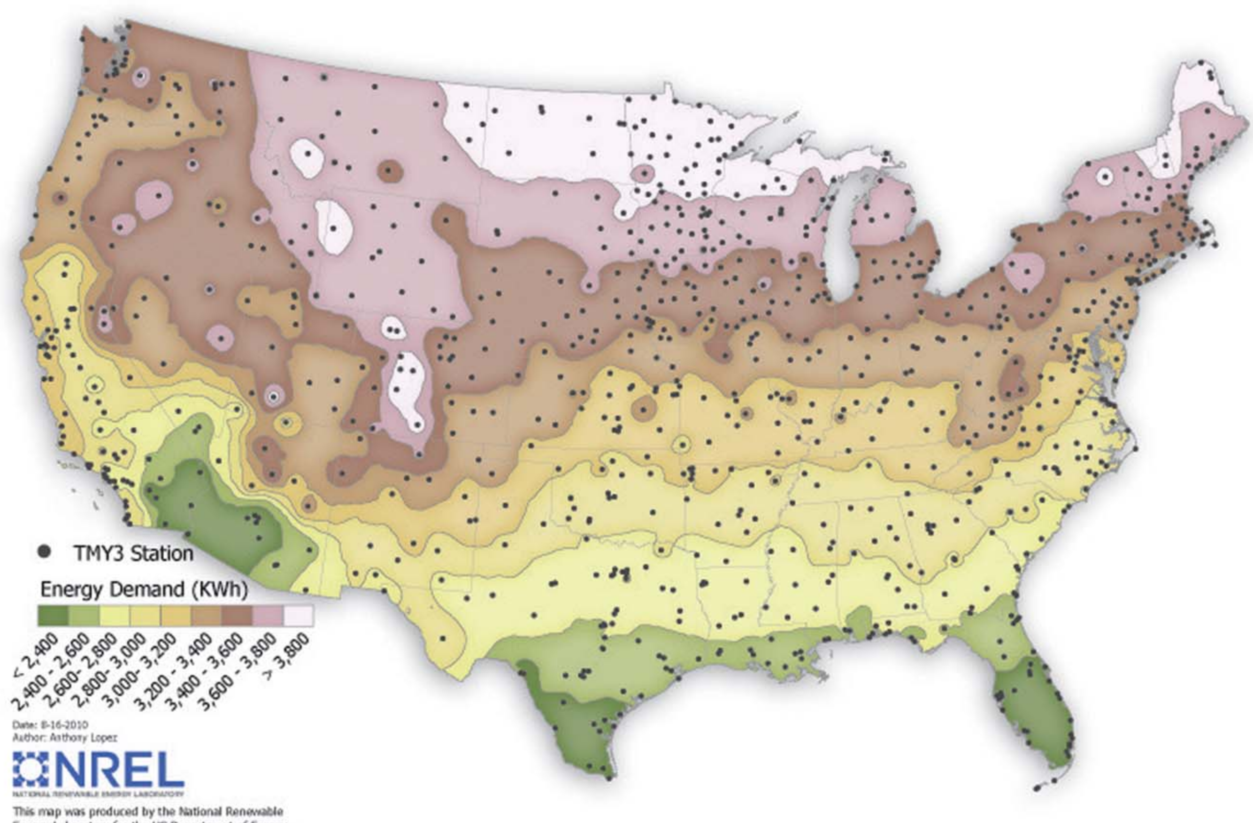

Fig. 2. Regional variation in annual hot water heating energy demand (kWh) for a single-family residence with a constant load profile (227 L/day).

and undersized in regions with low solar irradiation (such as the Pacific Northwest). Sensitivities to collector area are discussed in Section 3.

For the specified system, SAM calculates the thermal energy savings. Parasitic pumping energy (with pump power of 40 W for both solar loop and storage loop pumps) is automatically deducted from the useful output of the system (lowering the actual amount of energy produced by approximately 10 kWh per month). For each of the top 1000 electric utilities, a solar resource location (TMY3 station) was selected by choosing the location closest to the population-weighted center of the service territory in each state. California and New York were split into two regions due to large populations and discrepancy between electric utilities.

The electric energy savings of the base case SWH system across the United States is presented in Fig. 3.

As shown in Fig. 3, New Mexico and Colorado have the highest energy savings, exceeding 2400 kWh per year. Except for southwestern Arizona and northern Montana, all states in the Mountain region save over 2000 kWh annually, as do many in the Midwest. States in the Middle Atlantic and Pacific Northwest generally have lower energy savings, dropping below 1800 kWh annually. The amount of energy saved is primarily driven by climate factors such as solar resource, cloud cover, precipitation, and inlet water temperature. The higher the inlet water temperature (as in Arizona), the less energy required for water heating, and the lower the quantity of energy saved. Areas with high amounts of annual precipitation and cloud cover (such as Oregon, Washington, and Ohio) have less solar energy available for water heating. States with year-round good solar resource and cooler inlet water temperatures (such as Colorado) will have high energy savings.

2.4. Regional variation in solar fraction

The solar fraction is a performance metric that indicates how much of the energy demand is supplied by the SWH system. It is typically expressed in terms of percent of total load met and varies between 0% (no SWH system) and 100% (all energy supplied by the SWH system). On winter days or days with inclement weather, the SWH system may meet none of the daily hot water demands, whereas on sunny, summer days, the system may save more energy than is required to satisfy 100% of the hot water needs. This parameter will vary geographically and with time based on hot water usage and solar resource. Assuming a constant load profile for a single-family home, Fig. 4 illustrates the solar fraction of the base case SWH system over the contiguous United States.

As shown in Fig. 4, the solar fraction is highest in the Southwest and southern Florida and decreases toward the north and east of the country. Arizona and Florida have the highest solar fractions, exceeding 85%, while in northern Washington, Minnesota, and Michigan, the solar fraction drops below 45%.

Seasonal variations in the solar fraction are also significant. Depending on the amount and consistency of the solar resource over the course of a year, there may be considerable variation in the solar fraction for a given location from month to month. A system that has a solar fraction of 100% during any time of the year is oversized and curtailment occurs, indicating that more solar energy is available than can be utilized by the system. A smaller system size reduces the amount of energy curtailed. The relationship between break-even SWH system cost and solar fraction is discussed in Section 3.

2.5. Fuel prices and value of energy saved

The net present benefit (NPB) realized to the consumer is based on the discounted cumulative benefits of reduced electricity bills over the evaluated period, driven by the local SWH system performance, hot water usage, and electricity rate. The NPB is highly sensitive to the price of electricity and the daily hot water draw. In this analysis, we considered only flat rates for electricity—due to the high level of variability in hot water usage, it is difficult to estimate the impact of time-of-use rates.

The break-even cost for SWH was calculated for the top 1000 electric utilities in the United States, which represent about 97% of the total residential load. To determine local electricity rates, a scaling parameter [14] was generated from the largest electric utility tariff sheet in each state and the EIA monthly and annual utility data for 2008 [2,19].

Using monthly simulation data from SAM, we multiplied the output of the SWH system by the monthly electric price and summed over a year to determine the weighted annual average value of the energy saved ($). The first year values for the largest utility in each state are presented in Fig. 5.

As illustrated in Fig. 5, locations with a combination of high energy production and high electric prices have a high value of the NPB. About 10% of residential electricity sales are in utilities that have energy savings greater than $300/year, while less than 3% of residential electricity sales are in utilities with energy savings less than $100/year.

2.6. Break-even costs

We define the break-even cost of SWH as the point at which the NPC of the SWH system equals the NPB realized to its owner—the difference between the NPB and NPC yields the NPV of the system. This can be used to find the installed system cost ($/system) required for a given fuel price. By definition, a SWH system is at break-even or better when its installed cost falls below the break-even value. For example, in an area with a break-even cost of $7000, all SWH systems that have an installed cost of less than $7000 are below break-even. The break-even system cost was calculated by iteratively varying the price of SWH until the NPC equaled the NPB.

The NPC is the cumulative discounted cost of the system, including initial cost, financing, tax impacts, incentives, and O&M, equal to the sum of the cost in each year multiplied by the discount factor in that year.

$$\mathrm{NPC} = \sum_{y=0}^{N} \frac{\mathrm{Cost}_y}{(1+d)^y} \tag{1}$$

where d is the discount rate and y is the year.

In the base case, we assume the system is financed and the initial cost (or cost in year zero) is equal to the down payment minus any rebates. The annual cost in subsequent years is

$$\mathrm{Cost}_y = \mathrm{Loan\ Payment} - \mathrm{Interest\ Deduction} + \mathrm{O\&M} \tag{2}$$

The loan payment is based on the loan amount:

$$\mathrm{Loan\ Payment}_y = (\mathrm{Initial\ Cost} - \mathrm{Down\ Payment} - \mathrm{Rebates})\frac{i(1+i)^n}{(1+i)^n - 1} \tag{3}$$

where i is the interest rate and n is the loan term in years. The interest deduction or tax savings on the loan interest in each year is given by:

$$\mathrm{Interest\ Deduction}_y = \mathrm{Marginal\ Federal\ Tax\ Rate} \times i \times \mathrm{Current\ System\ Balance}_y \tag{4}$$

where Current System Balance$_y$ is the loan amount that has not yet been paid off.

Some incentives (such as tax incentives) may not occur until a year or so after installation. These incentives are discounted by one year.

The NPC in our base case scenario assumes a system financed with a home-equity-type loan (with tax-deductible interest and a

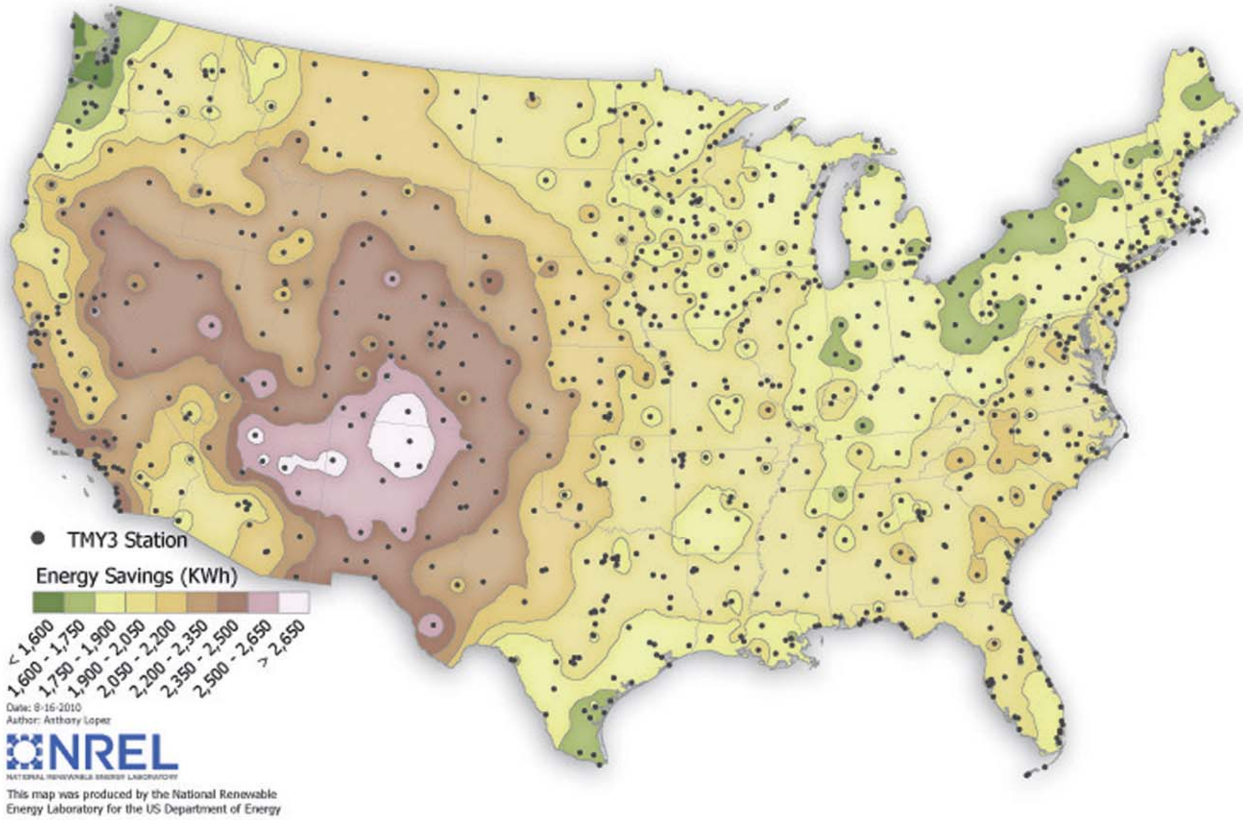

Fig. 3. Variation in annual energy savings (kWh/year) for the base case SWH system with an electric auxiliary water heater.

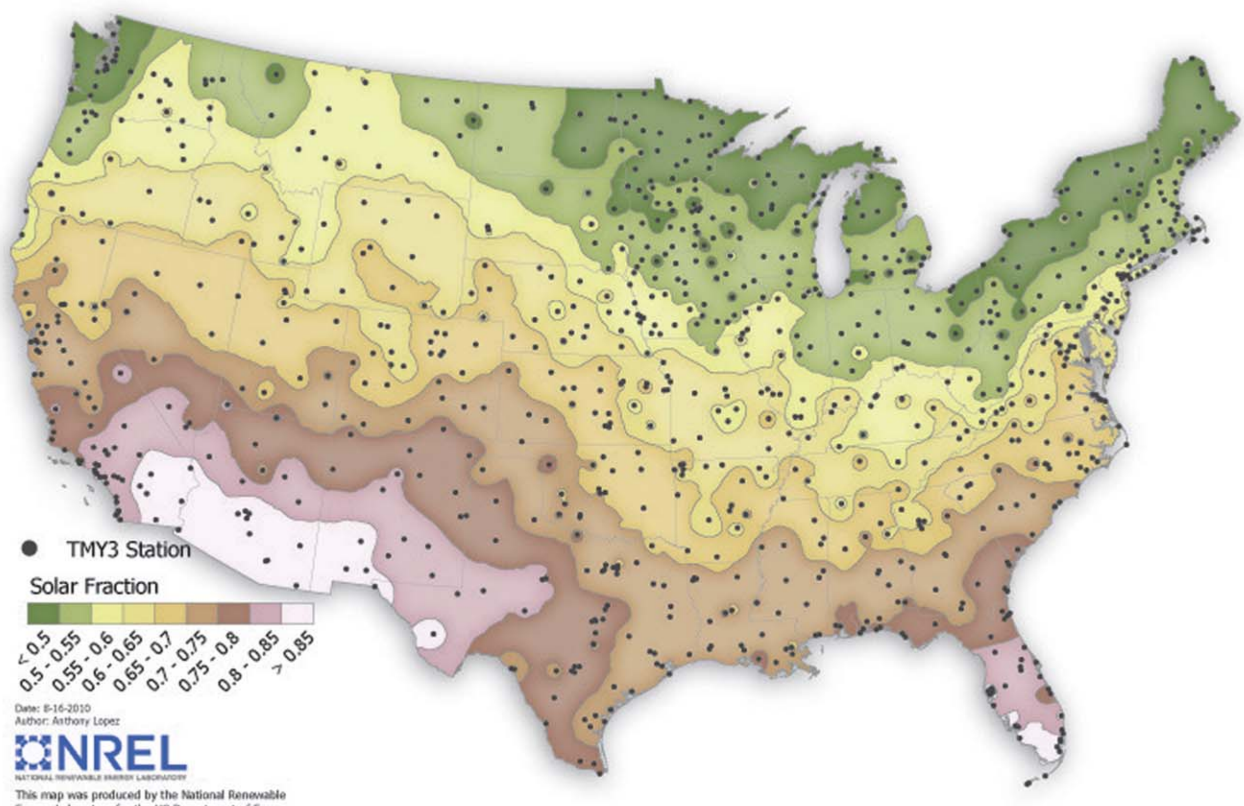

Fig. 4. Variation in annual solar fraction (percent of daily load met by the SWH system) for the base case SWH with an electric auxiliary water heater.

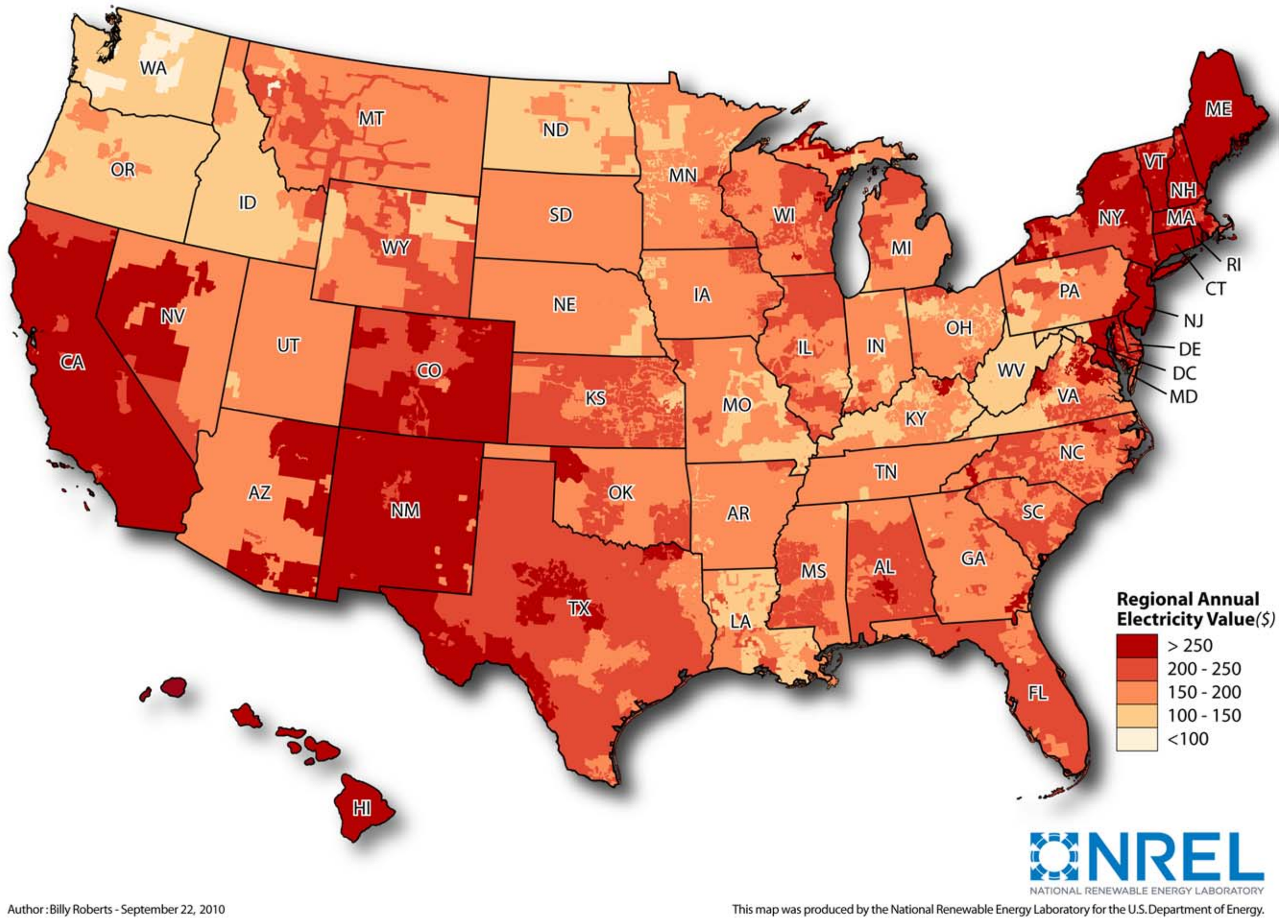

Fig. 5. Annual value of energy saved ($) for the base case SWH system with an electric auxiliary water heater for the top 1000 residential electric utilities.

28% marginal federal tax rate), a 20% down payment, a real interest rate and discount rate of 5%, and a loan term of 30 years.[2] The evaluation period for the analysis was 30 years (this implies an expected 30-year life of the system). Operation and maintenance on the SWH system is composed of tank and heat exchanger fluid replacement at 10 and 20 years. It is assumed that the cost of these replacements is $1000 every 10 years.

The analysis considered several incentive programs, including the 30% federal investment tax credit (ITC), as well as known state, local, and utility incentives derived from the Database of State Incentives for Renewable Energy (DSIRE) as of June 14, 2010 [20]. Where multiple incentive programs are available, they are assumed to be additive (this is the case for most but not all incentive programs). Tax credits were applied at the end of year one in the NPC calculation. When considering rebates, their taxability and effect on the federal ITC must be considered. In our base case assumption, we assume that the rebate is paid to the installer rather than the homeowner. This effectively reduces the installation price to the homeowner by the amount of the rebate and also reduces the basis for the federal ITC. The actual treatment of incentives varies depending on their type and source. The primary alternative treatment of incentive taxability occurs when the incentive acts as taxable income but does not decrease the basis for the federal ITC. In reality, with our assumption of a marginal tax rate of 28%, the difference in break-even price is quite small.

This analysis makes several assumptions that are generally favorable to SWH. First, it assumes that SWH systems are exempt from sales tax, which is true in some but not all states. In states where SWH systems are taxed, the break-even cost would be reduced by a percentage roughly equal to the sales tax rate. Second, the analysis assumes that SWH systems are exempt from property tax, which is also true for many but not all regions and states. For a list of states and localities that exempt SWH systems from sales and property tax, see DSIRE [20].

Overall, the combination of factors described above represents a customer with excellent home orientation and access to attractive financing but who places no additional value on locally produced renewable energy. Sensitivities to these assumptions will be evaluated in Section 4.

The NPB is the discounted cumulative benefits of reduced electricity bills over the evaluated period or the sum of the benefits in each year multiplied by the discount factor. In the base case, we assume that electricity has a real price escalation of 0.5%/year. This is a real price escalation (before the effects of inflation). Estimates of future electricity prices are highly uncertain, and sensitivities to this assumption are provided in the next section. For reference, the EIA's Annual Energy Outlook 2009 [21] projects an annual real increase from 2008 to 2030 of 0.4%.

As discussed previously, the break-even point is found by iteratively increasing the cost of the SWH system or the fuel cost

[2] Here and elsewhere, we use real interest rates as opposed to nominal interest rates. The relationship is real interest rate = nominal interest rate − inflation rate. To calculate the nominal interest rate, an average inflation rate must be assumed. Our assumption of a 5% real interest rate is based on the 2008–2009 average home equity loan rate of about 8% and the average inflation rate of about 3% during this period.

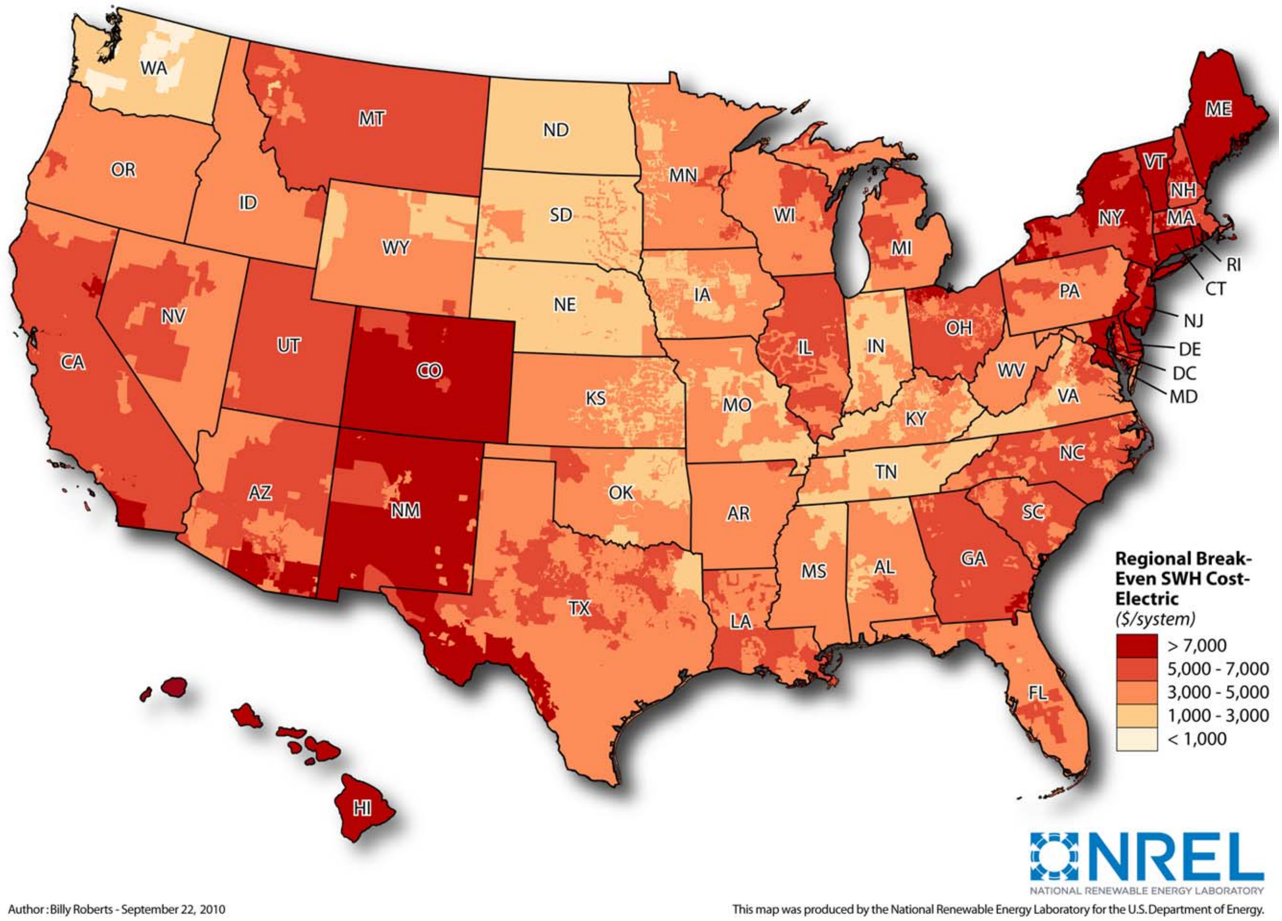

Fig. 6. Residential SWH break-even cost ($/system) for the top 1000 electric utilities (as of 2008) for a SWH with an electric auxiliary water heater and using all incentives.

until the NPC equals the NPB over the evaluation period. A spreadsheet/Visual Basic for Applications tool [22] was utilized to perform the financial calculations.

Fig. 6 provides the break-even cost of SWH ($/system) needed in the base case electric rate scenario for the largest utility in each state. All assumptions are identical to those of the base case.

When considering the results presented in Fig. 6 and elsewhere, readers should note that this analysis represents a single point in time. Because incentives and fuel prices are constantly changing, results for any single area may be substantially different when evaluated later.

Fig. 6 indicates that the only areas where a SWH system is at break-even or better is where there is a combination of high electricity prices (as in Hawaii and much of the east coast), good solar resource (as in Hawaii, Colorado, and New Mexico), and local incentives. At the base case assumption of $7000/system, break-even conditions currently exist in 73 utility service territories (serving 16% of the total residential electricity demand). This means that in these service territories, the break-even cost is above the assumed SWH system cost of $7000. If the cost of a SWH system were to drop to $5000/system, break-even conditions would exist for 366 electric utilities (51% of the total residential demand). It is important to note that in practice, only a fraction of customers in these utility service territories are likely to meet all the criteria (good solar exposure, good incentives, and financing) to be at break-even, and the presence of break-even conditions does not necessarily equate to large consumer adoption. Furthermore, there are budget caps for most current incentive programs [20]. Again, note that this is not a depth of market analysis and only a fraction of customers are likely to meet all the criteria for break-even.

2.7. Components of break-even costs

The total break-even cost in each location is the sum of the value of SWH from the fuel savings and the additional value derived from incentives. This is illustrated in Fig. 7, which shows the break-even cost for the largest utility in select states along with a distribution of the break-even cost components, including the net value derived from the electricity savings [includes both operation and maintenance (O&M) expenses of the solar system and annual revenues in electricity savings], the effect of the home-equity-type loan, and federal and local incentives. The black line indicates the break-even cost without any federal or state incentives. Also included are error bars indicating the range in break-even values for the largest 1000 electric utilities. California was divided into two sub-regions, northern and southern, due to its large size. New York was also divided into two regions due to the large differences between the New York City/Long Island region (together labeled “NYC”) and the remainder of the state (labeled “NY”).

As shown in Fig. 7, the break-even SWH price shows significant variability. In some cases, the break-even value for the most attractive utility is several thousand dollars more than the break-even value for the largest utility. However, these more attractive utilities tend to be significantly smaller than the largest utility, often providing less than a few percent of the state’s sales. For electricity, we see break-even prices above $7000/system in only a few places without local incentives. In addition, without local incentives or

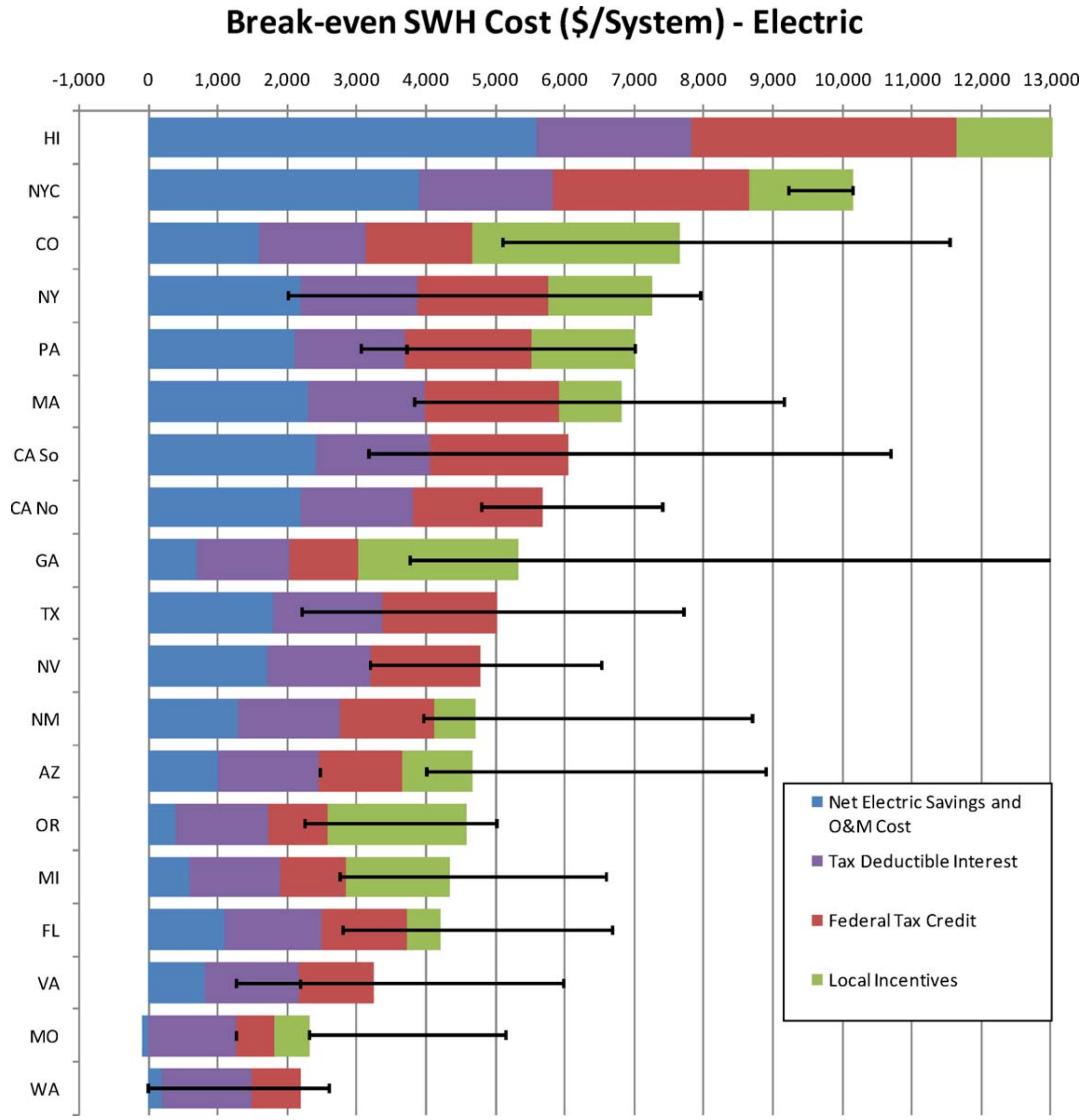

Fig. 7. Components of the electric break-even value and range in break-even value for select states (as of June 14, 2010).

the federal ITC, two-thirds of the largest electric utilities in each state have a break-even cost of under $3000/system. Missouri is one of three states which have a negative value for the net electricity savings. This indicates that the savings in electricity were not sufficient to cover the O&M expenses of the system. The factors affecting break-even cost are discussed in more detail in Sections 3 and 4.

3. SWH system size and performance

As noted in Section 2.4, the technical performance of the SWH system is a function of the system size, determined by the area of the solar collector. For a country like the United States with significant spatial variation in solar irradiation, different system sizes may be optimal for different geographic locations. Large collector areas tend to absorb more solar energy, thus yielding a higher solar fraction. However in locations with high solar irradiation large systems may be oversized resulting in curtailed energy savings.

3.1. Energy saved as a function of collector area

In the United States, four discrete system sizes are common for SWH installations, as specified by the area of the collection surface: 2.97 m^2, 3.72 m^2, 5.95 m^2, and 7.43 m^2. Most installed systems have a collection area of either 3.72 m^2 or 5.95 m^2. Fig. 8 shows the energy saved (in kWh) versus collector area (in m^2) for a small subset of states for each of the four typical system sizes.

As illustrated in Fig. 8, the amount of energy saved follows a curve of diminishing returns. Initially the increase in the amount of energy saved per unit area is high; however the curve levels out between the two larger system sizes, 5.95 m^2 and 7.43 m^2. Depending on the state, the rate at which the curve flattens may vary considerably. States such as Florida or Hawaii (with minimal annual climate fluctuations) show little increase in energy savings between 3.72 m^2 and 7.43 m^2, while states such as Colorado, New York (City), and Washington show a dramatic increase even between 5.95 m^2 and 7.43 m^2.

3.2. Range in break-even and solar fraction by collector area

In order to determine how much more (or less) a SWH system could potentially cost based on its solar fraction (influenced by the size of the system), relationships between SWH cost and solar fraction were developed for each state and are presented in

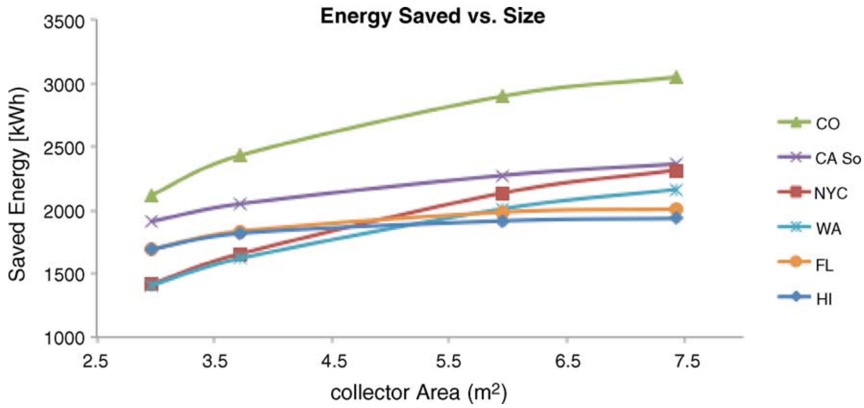

Fig. 8. Curve of energy saved versus collector area for four discrete system sizes and select states.

Fig. 9. For a given location, systems with large collector areas or improved performance (due to higher quality materials, glazings, and insulation, for example) will have higher solar fractions than systems with small collector areas or lower quality materials. To determine the relationship between SWH cost and solar fraction, the base case break-even SWH price was plotted against solar fraction for three typical system sizes: 1.86, 3.72, and 5.57 m^2. The base case scenario utilizes a 3.72 m^2 collector area. The low value could represent either a system with a smaller collector area or decreased performance (unglazed, no cover), while the high value could represent a system with a larger collector area or improved performance (dual covers, improved glazing). It is important to note that an increased solar fraction may not necessarily correspond to an economic advantage. Oversized systems will be curtailed, and excess energy will not be utilized. For states with a high solar resource, Fig. 9 may be utilized to determine how much *less* the SWH system could cost in order to maximize use of the energy collected.

Fig. 9 shows the base case SWH break-even cost and solar fraction (represented by blue and purple bars respectively) for select states for a 3.72 m^2 collector area, in addition to error bars representing the break-even cost and solar fraction for both a 1.86 m^2 collector area (low end of error bars) and 5.57 m^2 collector area (high end of error bars). For a number of states, the base case system size already has a high solar fraction, which means that many of the error bars are skewed toward the lower value. This indicates that increasing the system size or performance does not yield a significant increase in the amount of energy produced.

The SWH break-even cost varies linearly with solar fraction, indicating that for a given state, direct interpolation is possible between the two error bars to determine the SWH break-even cost corresponding to a system with a different solar fraction than that shown in Fig. 4.

The results presented above may be utilized to determine if a more expensive system with a higher solar fraction is economical. For example, for a SWH system in Colorado, the base case break-even cost is \$7660 with a solar fraction of 70%. To determine what the SWH break-even cost should be for a system with a solar fraction of 80%, it is necessary to find the point along the error bar for solar fraction that corresponds to 80%. Since this point appears to lie nearly at the high end of the error bar, the break-even SWH system cost should also lie near the high end of the error bar, or at approximately \$8500. If a SWH system with an 80% solar fraction in Colorado is available for less than \$8500, then it would be at break-even.

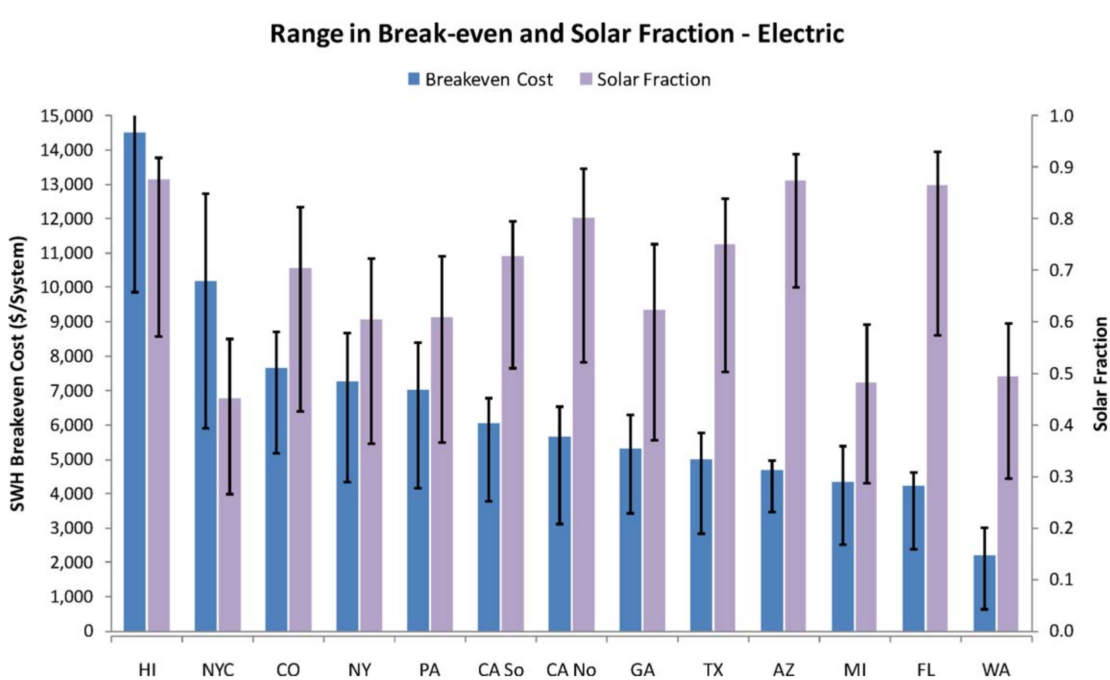

Fig. 9. Range in SWH break-even cost and solar fraction for select states for a SWH with an electric auxiliary water heater.

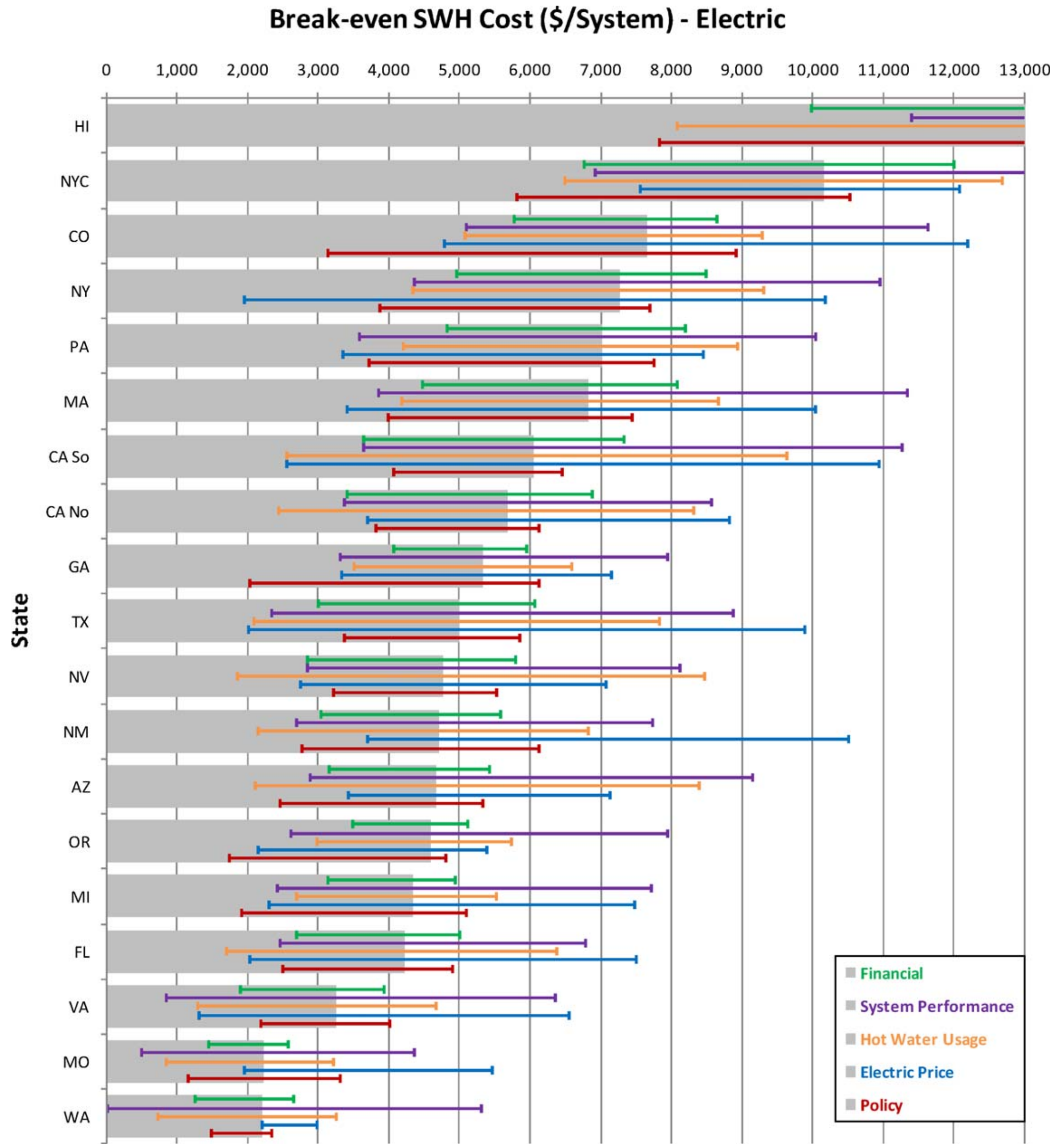

Fig. 10. Range of SWH break-even costs for select states.

4. Market sensitivities of break-even costs

The high break-even costs in many states that were noted in the previous section are driven primarily by state, utility, and federal incentive programs. Incentive programs are designed primarily to encourage the development of SWH markets; however, over time they are expected to be phased down as the cost of SWH systems decrease and SWH markets become self-sustaining. In this section, we consider the sensitivity of SWH break-even costs to a set of five classes of impacts: financing, system performance, hot water usage [23], fuel cost, and policies. Table 1 lists the base case and the five sensitivity cases evaluated. The values used in Table 1 are not intended to represent all possible scenarios but were chosen to provide a reasonable range of values for each parameter.

Fig. 10 provides the results of the sensitivity analyses for select states. In each state, a base case break-even cost based on the largest utility in the region is provided; five error bars show the range of break-even costs for the sensitivity cases. Each of the five drivers has a low case and a high case. The low case, which decreases the economic performance of SWH and moves the error bar left, represents a lower break-even cost. Examples include lower SWH output from non-optimal orientation or a premature elimination of the federal ITC. The high case represents improved economic performance, increasing the break-even price. Examples include a higher solar fraction (perhaps corresponding to a larger system) or a larger effective cost of carbon. The scenarios and error bars in the figures are partially additive. For example, both a more aggressive carbon policy and a high solar fraction could occur, increasing the break-even cost more than these factors individually. However, these factors are not completely additive; for example, the highest solar resource location in each state may not correspond to the highest price region.

As shown in Fig. 10, the base case break-even price is between $2200/system and $10,160/system (excluding Hawaii and Alaska). Fig. 10 shows that system performance (including solar resource location, system orientation, and size) is the biggest driver of break-even price variation, followed closely by electricity price, then hot water usage, policy issues, and finance factors. The variation in

Table 1
SWH sensitivity cases.

Base case		Financial		System performance		Hot water usage		Fuel price		Policy	
		Low	High	Low	High	Low	High	Low	High	Low	High
Down payment	20%	20%	0%								
Federal tax bracket	28%	20%	35%								
Discount rate	5%	7%	4%								
Interest rate	5%	7%	4%	Base	Base						
Loan type	30-y home equity	15-y home equity	30-y home equity								
Evaluation period	30 y	20 y	30 y								
Tilt	26.5°			15°	26.5°	Base	Base				
Azimuth	360° (S)			45° (SW)	360° (S)			Base	Base		
System size (collector area, volume)	3.72 m², 227 L			2.97 m², 182 L	5.95 m², 363 L					Base	Base
Water heater energy factor (Elec)	0.9			0.8	0.98						
Solar resource location	Largest utility			Lowest	Highest						
System degradation	0.5% per year			0.5%	0%						
O&M	$1000 per 10 years	Base	Base	$1500	$500						
Hot water draw	227 L/d					114 L/d	379 L/d				
Water heater set temperature	48.9 °C					48.9 °C	60 °C				
Real fuel price escalation	0.5% per year							0%	1.5%		
Fuel cost location	Largest utility			Base	Base			Lowest	Highest		
CO_2 cost	$0					Base	Base			$0	$25/ton
Incentives	DSIRE (6/14/10)							Base	Base	None	DSIRE (6/14/10)

the solar system parameters is primarily due to the solar resource location and system size. The impact on break-even costs is large for all states; however, there is also a high level of variability from state to state, from about a ±40% to ±90% impact. The variation in the electricity prices is due more to the spread between utilities within a state than the variation in the price escalation assumed. Hot water usage assumptions result in a roughly symmetrical impact on break-even costs, also with a large range—from ±30% to ±60% by state. The ITC is the single largest policy driver evaluated. Availability of system financing was the least important sensitivity case, generally only affecting the break-even SWH cost by ±20%.

Each of the five impact categories reported in Table 1 combines several drivers, obscuring the contribution from each. For example, the break-even cost is highly sensitive to the daily hot water draw and system size, both of which can have relatively large ranges, which increases the range of break-even costs due to these factors. While the water heater energy factor or system degradation may also have an impact on break-even costs, these factors can only vary by a small amount and are difficult to separate out from the other highly variable factors in each category. It appears that the primary drivers of the system performance category are the system size and O&M. Solar resource location has a variable impact—for certain states (especially large ones) the difference between solar resource locations is significant (Arizona, Illinois, and Texas), whereas for smaller states the difference can be quite small.

5. Conclusions

Current solar water heating technologies in the U.S. have the potential to save approximately 50–85% of the energy used for this application depending on region. For systems currently using electricity for water heating, this corresponds to an annual savings in the range of under 1600 kWh to over 2600 kWh for a typical household and an annual bill savings of about $100 to over $300. This range in technical and economic performance means the current break-even price of SWH varies by more than a factor of five. This difference is largely driven by incentives, which can exceed $3000/system, and the difference in electricity prices, which can vary by a factor of four. Even without incentives, large variations in break-even cost will remain given the range of hot water usage and solar energy available.

The general trend observed in this analysis is that SWH systems that replace conventional electric systems are more likely to achieve break-even costs in areas with either high electric prices (such as in the Northeast) or high solar resource (in the Southwest). Very low electricity prices and moderate system performance will preclude break-even conditions in certain areas in the Northwest and Midwest unless SWH system costs drop substantially.

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